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MINE DETECTION BASED ON TRACE EXPLOSIVE DETECTION (TED)

by

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ABSTRACT

A landmine detection prototype based the detection of residual explosives in soils was tested in 1996 on a landmine field located at DRES. The minefield included 25 buried mines, 25 empty sites and one with a TNT block buried in the soil. In order to evaluate the efficiency of the system, the detection of explosives (TNT and RDX) was performed on these 51 sites. The detector could not detect the presence of mines due to the low concentration of explosives on most sites with mines. A preliminary evaluation of the explosives contained in the soil was also performed. It showed a concentration of explosives below the detection limit of the prototype (0.8 ppb w/w TNT and below 7.4 ppb w/w for RDX). Higher concentrations in the soil were determined in this minefield in 1997 and 1998 and they showed increased concentration with time. These complementary results have been published in an additional DREV report. Higher concentrations of explosives in the soils should also be present in the cases of an activated mine (with the fuze) in warmer and dryer weather conditions. These favourable conditions may be encountered in many countries with buried mines. However, for security purposes, we have not performed experiments with activated landmines in such conditions.

RÉSUMÉ

En 1996, on a évalué au CRDS un détecteur de mines basé sur la détection des explosifs résiduels dans les sols. Le champ de mines contenait 25 mines enfouies, 25 sites vides et un site contenant un bloc de TNT. Dans le but d'évaluer la performance du système on a effectué la détection d'explosifs (TNT et RDX) sur ces 51 sites. Le détecteur n'a pu mesurer la présence de mines en raison de la trop faible concentration d'explosifs dans la plupart des sites minés. On a également procédé à l'évaluation préliminaire des explosifs contenus dans le sol et observé des concentrations d'explosifs en-dessous de la limite de détection du prototype (0,8 ppb p/p TNT et 7,4 ppb p/p RDX). On a détecté une plus forte concentration dans les sols sur ce site en 1997 et 1998. Les résultats montrent d'ailleur un accroissement de la concentration. Ces résultats complémentaires ont été publiés dans un rapport du CRDV. On devrait mesurer de plus fortes concentrations d'explosifs dans le sol dans le cas de mines activées (avec les détonateurs) et dans des conditions plus chaudes et plus sèches. Ces conditions plus favorables se retrouvent dans plusieurs pays ayant des mines enfouies. Cependant, on n'a pas expérimenté de telles conditions sur des mines activées pour raison de sécurité.

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EXECUTIVE SUMMARY

Trace Chemical Detectors (TCD), commonly called sniffers or electronic noses, have been used for the identification of hidden bombs for security purposes, for narcotics identification in the struggle against drugs dealers and also in food industries. It has been suggested that Trace Explosive Detectors (TED) technologies could be used as a hand held landmine detector or as a means of certifying areas without landmines. However, no major work has completely addressed this topic, which covers the sensitivity requirements of a system and the technical improvements for the construction of a TED landmine detector. To answer some of these questions, a research program on TED technologies has been persuaded in Canada for five years, mainly for landmine detection applications. Field trials and technical investigations were performed with commercial sniffers to evaluate the difficulties of using this technology as a hand held landmine detector. Calculations with theoretical models were performed at DREV. They showed that vapours of explosives at the soil surface would be very difficult to detect in any cases. Work has also been reported by DREV and by T.F. Jenkins et al. (US-CRREL) on the quantities of explosive-related chemicals found in the soil at the surface of an unactivated buried landmine (no fuze). Nevertheless, there has no complete evaluation of the residual-explosive related chemicals in various weather conditions (warm and dry countries) and with activated mines has been peformed. The very low sources of vapours encountered has led to define the concept that detecting the explosives directly in the soil would be a better way than detecting the vapours at the soil surface. As a consequence, a landmine detector prototype based on the detection of residual explosives in soils was developed in Canada.

This report contains the results of a field trial performed by using the developed landmine detector prototype. It also contains a summary of the problems in the detection of landmines with TED in general or by using an electronic nose or dogs. With the trace quantities of explosives found in most soil samples, it is still unclear how dogs can detect buried landmines. It was suspected that the presence of the fuze on an activated mine in warm and dry conditions could lead to more favourable detection conditions (encountered in some countries). However, such experiments were not performed for security purposes.

ABBREVIATIONS

AP : Anti-personnel mine
AT : Anti-Tank mine
CRDV : Centre de recherches pour la défense Valcartier
CRREL : US Army Cold Regions Research and Engineering Laboratory
DNT : 2,4-Dinitrotoluene
DRES : Defence Research Establishment Suffield
DREV : Defence Research Establishment Valcartier
EPA : Environment Protection agency
GC/IMS : Gas Chromatography/Ion Mobility Spectrometry
HPLC : High Performance Liquid Chromatography
IMS : Ion Mobility Spectrometry
ppb v/v : part per billion (10^{-9}) of vapours in Volume/Volume
ppb w/w : part per billion (10^{-9}) of solids in Weight/Weight
ppt v/v : part per trillion (10^{-12}) of vapours in Volume/Volume
ppt w/w : part per trillion (10^{-12}) of solids in Weight/Weight
TED : Trace Explosive Detectors
TNT : 2,4,6-Trinitrotoluene

1.0 INTRODUCTION

The potential of Trace Explosive Detection (TED) technology to detect mines resides mainly in the fact that soil will invariably be contaminated with trace quantities of explosives. It is suspected in a first step that the staff burring landmines is likely to inadvertently contaminate the soil with trace quantities of explosives found on their boots, hands, gloves, amunition vehicle, on the shovel and on any burial equipment. However, from our experience acquired in additional studies (Refs 1,2,3) the major source of explosives contamination is probably coming the vapour emission through the mine casing, through the seal and seams or through the fuze. As a matter of fact, the residual explosives on mines casing has been recently determined to be in the range of ng/cm^2 by Jenkins et al. (Refs 4-6). As a consequence, the explosive found at the surface of the casing is the sources of explosive-related chemical released in the soil. The resulting contaminated soil over the mines is becoming the main source of explosive-related chemicals to be detected with TED technology.

It should be specified that the TED instruments available on the market have been mostly designed for bomb identification rather than for landmine detection purposes. Some authors have stressed the possibility of using an explosive detector as a sensor for buried landmines (Refs.7-10). In order to evaluate the potential of the technology, technical investigations were performed in Canada, by simulated studies (Refs. 11-14), in the US by the analysis of volatile impurities contained in explosives from mines (Refs. 15-23), by detection of explosives with enzymatic methods (Refs. 24-26) and by laser-based explosives detectors (Ref. 27). More recently, a considerable US effort was performed through DARPA financial support to evaluate electronic nose technologies and to develop a hand held system based on the detection off the residual explosives (Refs 28-30). Evaluations of the movement and availability of explosive vapours from buried landmines have also been performed using experimental models (Refs 31-33). A complete study on the explosives contained in the soil has been reported recently by Jenkins et al. (Refs. 4,5) and at DREV by Désilets et al. (Ref 1). Additional theoretical evaluations of the residual explosive vapours at the surface of the soil have been performed by Phelan and Web (Ref. 34) and also at DREV (Ref. 2). These results showed that the vapour source of explosive-related chemicals, such as TNT, 2,4-DNT, are below 8,3 ppq v/v (10^{-15}) and 12 ppq v/v (10^{-15}) at the surface of the soil. Such technical investigations and measurements of residual explosive vapours have yet to be considered for the further design of a landmine detector based on a sniffer.

Between 1994 and 1999, a prototype has been developed for applications in landmine detection (Refs. 35-36). At the beginning of this work, a field trial was performed on buried landmines in December of 1994 (Ref. 3) by using three commercial TED systems. The aim of this trial was to evaluate the potential of detection and to determine the technical modifications required to detect landmines. From the field trial results (Ref. 3) combined with theoretical (Refs. 2, 33 and 34) and technical Canadian investigations (Refs. 11-14), it is clear that the vapour pressure of RDX, TNT or 2,4-DNT is too low (Ref. 37) to be detected by conventional sniffers designed for bomb detection. In fact,

the explosive vapours coming from the surface contamination of the mine or from leaks in the mine casing are greatly reduced by the soil barrier over the buried mines. Based on our experiences with most buried landmines, potential landmine detector based on vapour detection would need a sensitivity to explosives vapour concentrations much lower than the ppq v/v (10^{-15}). Considering that a dog nose and TED technologies are sensitive to vapours at the ppt v/v level (10^{-12}) it is quite clear that the vapours coming from buried mines are not detectable with current TED systems or with trained dogs (Refs. 37-43). However, it is suspected that the presence of the fuze in some types of mines may lead to higher residual explosive related materials in the soil. In this ideal scenario, it is suspected that dogs may detect explosives in the soil but not in the vapour phase.

A system with a sensitivity at the very low level of vapours required for mine detection applications (fraction of ppq v/v, 10^{-15}) is hard to design with current TED technologies (Refs. 44, 45). A very performant preconcentrator system, which would strongly trap the explosives vapours contained in a very large volume of air and concentrate the traces on an absorbent surface within an acceptable period of time would be needed (Ref. 46). Such preconcentrator would probably need a more sensitive detector than a current one. Consequently, it led to define the concept that detecting residual explosives contained in the soil particles or in dirt could be a better way to detect buried land mines. Such a detector could be used as a confirmatory technology on a multisensor vehicle. We have thus oriented our research towards the development of a prototype (Ref. 36) that collects samples using a vacuum followed by an extraction of the residual explosives bounded to the soil with an appropriate solvent under pressure and temperature. The traces of explosives contained in the soil (as opposed to vapour detection) were then detected in a low concentration, down to around 1 ppb (10^{-9}) w/w for TNT and RDX. The TED sensor used for the prototype was based on Ion Mobility Spectrometry technology (IMS), formerly known as plasma chromatography (Refs. 47-50). A gaz Chromatography column (GC) specifically designed for this application, was developed and adapted with the IMS system. The system developed made it possible to reduce the detection limit of explosives in soils at a level never reached before with the IMS technology and possibly not reached with any other commercial TED systems. The prototype was designed with the expertise acquired over years of development (Ref. 35).

This report contains the results of a detection trial performed with the landmine detection prototype at the Defence Research Establishment Suffield in November 1996. The system was based on detection of explosives by soil sampling made over the buried landmines. The main objective of this trial was to evaluate the potential of the TED prototype to detect which sites contained mines. This report also described a preliminary investigation of the residual explosives contained in the soil, which result from the landmine burial process. Complete evaluations of the residual explosives contained in the soil (at this minefield in 1998 and 1999) and in the vapour phases are also found in other DREV reports (Refs. 1, 2). This report also contains a summary of the problem encountered in the detection of buried landmines using TED technology.

2.0 EXPERIMENTAL PROCEDURES

2.1 Landmine Detector Prototype

Many technical modifications of the conventional IMS system were made for this specific application. The equipment collected a sample by vacuuming and used a sifter device which selected small particles of soil. It then robotically extracted the residual explosives with solvent to weaken the explosive bonded to the soil. The soil sample was then desorbed to reached a high sensitivity of detection down to 0.4 ± 0.1 ppb w/w for TNT and 7.4 ± 1.9 ppb w/w for RDX. A better description of the system can be found in a contract report (Ref 35,36) which includes the following aspects : design, construction and optimization of the experimental land mine detector. The performance of this system to detect mines on the field will be evaluated in section 3.2 of this report.

2.2 Preparation of the Mine Field

In order to avoid errors with possible seriously contaminated soil, the field prepared was totally clean of any explosives (not previously used for mine detection or any other activities relevant to explosive materials). The restricted area enclosed by security fences was prepared for various mine detection activities related to the D6300 project. The test track of approximatively 250 m long chosen for the TED trial was however available in September 1996.

All the mines planted were unfused and filled with TNT or with a mixture of TNT and RDX. Twenty anti-tank mines (AT) buried in the soil were used, with some recently planted and some planted two months before the trial. Five different types of anti-tank mines from various sources were used. Some additional anti-personnel (AP) mines were also buried. Other sites contained buried objects (cartridge) and one contained a pure block of TNT (3.6 kg) sealed in a plastic bag and buried two months before the trial. For statistical purposes, an equal number of empty sites were used (non-mine sites).

The burial was made by digging the holes two weeks before any item was planted. All the mines were then put directly in their corresponding holes. At no time was any mine placed on the surface of the road beside any hole prior to planting. Finally, the mines were covered with the soil one by one by using a clean shovel. The depth of buried mines was between 2-6 inches and considered not critical for the trial. All sites were identified on the ground by a coloured disk in the middle of the mine site. The sites were randomly numbered and separated by at least 5 metres in order to avoid cross-contamination between sites. The personnel who conducted the detection experiments did not known in advance which sites contained a mine. Table I summarize the 51 different sites on which we performed the detection with the prototype.

TABLE I

Summary of the various sites present in the mine field

AT Sites Previously Buried	AT Sites Freshly Buried	AP Sites Freshly Buried	Empty Sites (No Objects)	Object Buried
2 Type I[a]	2 Type I[a]	5[b]	20	5
2 Type II[a]	2 Type II[a]			
2 Type III[a]	2 Type III[a]			
2 Type IV[a]	2 Type IV[a]			1 TNT Block
2 Type V[a]	2 Type V[a]			

(a) Denotes the five different types of AT mines. (2 Type I: means two mines of type I)
(b) Five AP mines were present in the field

2.3 Procedure of Detection with the Landmine Prototype

The weather and snow covering the frozen soil in November prevented the use of the landmine detector directly in the minefield. The alternate procedure adopted was to remove the soil surface to perform the TED experiments inside a heated building. The sampling of the soil surface was carefully made with new plastic gloves for each site. The resulting 51 samples were kept in separated plastic bags. A first attempt at detection with the landmine prototype showed very low signal from the removed soil samples. Consequently, the samples were dried overnight at room temperature in aluminum pans. The dried samples were crushed and passed through a filter grid of 40 mesh. The detection of explosives was made with the prototype on the resulting samples of the 51 sites. Calibration with the empty and the spiked soil of 10 ppb was done many times during the readings of the various sites in order to get the best performance of the prototype.

2.4 Chemical Analysis of the Soil Samples by HPLC

Chemical analyses of the explosive contained in soils could have been performed by using the certified EPA 8330 method (Ref 51) developed at CRREL (Ref.52). This method as well as the colorimetric (Ref 53) and the immunoessay (Ref 54,55) methods, both available at Diagnostix inc., have mainly been developed for environmental purposes (Ref 56). Excellent articles on the explosives analysis in the environment has been recently published by Thiboutot et al (Ref. 56) and by Tomkins (Ref 57). The sensitivity of the standard EPA 8330 method is in the range of 0.25 ppm and 1ppm w/w, respectively, for TNT and RDX. Considering that the level of explosive we expected to encounter was in the ppb w/w level, we modified the EPA 8330 procedure for our needs. Analysis by GC-μECD or GC-ECD is also possible and has been used in other reports (Ref. 1).

The procedure used in this report was as follows: 100 g of the soil sample was added to nearly 100 mL of acetonitrile, manually stirred for about two minutes and placed in the ultrasonic bath for 12 hours. The supernatant with suspended soil particles was then filtered by using a 125mm 2V Whatman filter paper. The sand was washed twice with acetonitrile and the filtrate was made to 150 mL and placed in a 200mL Concentrator tube. The filtrate was concentrated down to 0.9 mL with an automated evaporator Turbo Vap II system. The small remaining volume of the acetonitrile containing TNT and RDX and the dissolved organic material of the soil was pipetted out and mixed with 2.7 to 4.6 mL of a $CaCl_2$ solution of 10g/L for salting out. The combined solution/water solution was then placed in a disposable syringe and filtered through a 0.45μm Teflon filter. In some cases, some insoluble organic material coming from the soil was eliminated from the acetonitrile solution by using a pipet. The filtrate was used for analysis by injecting 100 μL of the solution in the HPLC column. The eluent used for the HPLC analysis was composed of a mixture of 50:50 methanol/water. The C-18 reversed phase column of 5 μm with dimension 25cmx4.6mm was used. The diode array PDA-991M from Water was used and has a UV detector. The HPLC system used was the HP-1090 from Hewlett Packard.

The analysis was performed first with soil samples spiked with TNT and RDX at 1, 10 and 100 ppb. The resulting HPLC diagram of the spiked soils have shown a percentage of recovery for the extraction better than 65% for most samples analysed. The retention times of RDX and TNT peaks were of 4 and 7 minutes. The sensitivity of the modified method was reduced to ~0.1 ppb (10^{-9}) w/w. The expected limit of detection could have been slightly better. However, in most cases, because of the interference (present in the HPLC) from the other residual contaminants present in the soil, the sensitivity was in practice limited to ~0.1 ppb (10^{-9}) w/w. This is shown in a typical HPLC diagram on Figure 1 taken from a sample coming from a mine site. This analytical method was used to obtain the results in sections 2.5 and 3.1.

2.5 Investigation of the Residual Explosives in Soils

A study was performed in order to evaluate the level of the residual explosive present at a mine site. The technical evaluation of the contamination level covered the three following objectives:

1) To quantify the level of explosive transfered to the soil surface resulting from the handling of the mines by hand.

2) To quantify the level of explosives in the soil after two months of burial.

3) To quantify the evolution of the explosive level present in the soil surface after many months of burial.

The third objective comprising a complete study was performed in 1998 and 1999 and published in a DREV report (Ref 1). Experiments in controlled environments were performed in order to evaluate the amount of the residual explosive that can be transfered from the mines to the soil surface. For this experiment, three AT mines were first abundantly manipulated by three different people (comprising one ammunition technician) for a period of approximately three minutes. Each person has his own mine of a different type. Then, they used their contaminated hands to transfer the residual explosive by touching the soil surface as shown on figure 2b. The soil was gently manipulated in a first sampling procedure (Normal Handling) and then extensively manipulated (Extensive Handling) to collect a second sample. Ammunition technicians also made experiments in which they manipulated the soil with their gloves first and with their hands. The samples were air dried in order to avoid natural degradation of the explosives in soil samples (Which could be done by the microorganism contained in the soil). The chemical analyses of the resulting samples is shown on Table II of Section 3.1.

Because of the similar detection limit of the landmine detector prototype compared to the modified HPLC method, we decided to perform the evaluation of the trace explosive level (from the buried mines samples) with the landmine detection prototype. Consequently, an evaluation of the residual explosives contained at the soil surface after ten month was roughly performed with the landmine detection prototype. The evaluation of the TNT level in soil was made possible by using a calibrated solution. The calibration was made by using a solution containing 100 pg of TNT injected in the landmine detector system. The sensitivity of the signal was directly proportional to the quantity of explosives injected. The soil samples were then prepared by weighting 2 g of the soil, adding 2 mL of acetone and shaking for 3 minutes. Finally, the measurements were made by injection into the system of 1, 10, 20 and 30 µL of the extract. The results of the investigation is described in Section 3.3.

3.0 RESULTS AND DISCUSSION

3.1 Simulation Studies

Analyses of the eight samples taken from the handling experiment (transfer of the residual explosives to the soil after handling of the mines) was performed with the modified HPLC technique. In this case, the limit of detection was approximately of 0.1 ppb (10^{-9}) w/w for TNT and RDX. From the results in Table II, it can be concluded that the amount of transfer of explosive to the soil can vary depending on the mine type and on the degree of handling. In most cases, the TNT level contained in soils was below 0.1 ppb (10^{-9}) w/w.

We may now say that the contamination transfer to the soil by the hand was around the detection limit of the landmine detection prototype as well as the HPLC analytical method. It suggests that the land mine detection prototype would not be sensitive enough to detect the presence of mines immediately after the burial process. In only one case the residual explosive transfered to the soil was strong enough to be detected by the landmine detector prototype at the level of 3 ppb (10^{-9}) w/w for TNT and 20 ppb (10-9) w/w for RDX.

3.2 Detection Trial

The detection trial was performed with the land mine detection prototype on samples taken from the 51 sites. The first experiment performed on the site containing a block of TNT was very promising for the detection capability of the prototype. In fact, the TNT level contained in the soil was much higher than the limit of detection of the system. In this case the signal measured by the prototype was considered to be very strong. However, for the other sites the signals measured by the prototype were mostly at the same level as the residual noise. Based on the results in Table IV, it is evident that the sensitivity of the system was not enough to detect most mine sites. In fact if we combine the results for the AT and AP sites we have a percentage of correct identification of 60%. Considering the number of site we had, a statistical treatment was made possible. The preliminary results we have (with a 95% of confidence) showed that the correct identification score should be close to 50% for a chancy experiment (as opposed to the score obtained 60%). We would be tempted to conclude that the concentration level of explosives in some cases (1 to 2 sites for example) of the 25 landmine sites was enough to be detected by the prototype

TABLE II

Residual explosives transfer to the soil by handling of landmines

Mine Type - Handling Procedure	TNT	RDX
Type II - Normal Handling	ND	ND
Type II - Extensive Handling	3 ppb	20 ppb
Type V - Normal Handling	ND	ND
Type V - Extensive Handling	ND	ND
Type IV - Normal Handling	ND	0.8 ppb
Type IV - Extensive Handling	ND	1 ppb
Ammo. Tech. - Glove Handling	ND	0.7 ppb
Ammo. Tech. - Ext. Handling	ND	3 ppb

TABLE III

Detection results of buried landmine with the prototype

Mine Site #	Mine Type[a]	Signal TNT	Signal RDX	Detection Results[b]	Detection Identified[c]
Blank Soil		20	(30-100)	-----	-----
Spiked (10ppb/TNT)		200	-----	-----	-----
Spiked (50ppb/RDX)		-----	200	-----	-----
1	TNT Block	High	High	Y	Y
2	AP	188	-----	Y	Y
3	AT (V)	-----	-----	N	
4	Blank	-----	-----	N	Y
5	AT (III)	-----	-----	N	
6	Blank	-----	-----	N	Y
7	AP	-----	-----	N	
8	AT (III)	50	-----	Y	Y
9	AT (IV)	113	-----	Y	Y
10	Blank	142	-----	Y	
11	Blank	-----	-----	N	Y
12	Cartridge	-----	-----	N	Y
13	AT (II)	80	-----	Y	Y
14	AT (V)	-----	-----	N	
15	Cartridge	114	-----	Y	
16	Blank	175	149	Y	
17	Blank	44	105	Y	
18	AT (I)	101	104	Y	Y
19	Blank	-----	-----	N	Y
20	Cartridge	60	121	Y	

Mine		Signal		Detection	
Site #	MineType[a]	TNT	RDX	Results[b]	Identified[c]
21	AT (II)	-----	160	Y	Y
22	Blank	-----	-----	N	Y
23	AT (V)	120	128	Y	Y
24	Blank	-----	125	N	Y
25	Blank	-----	102	Y	
26	AT (IV)	45	110	Y	Y
27	Cartridge	-----	123	Y	
28	AT (I)	519	210	Y	Y
29	AT (III)	-----	136	Y	Y
30	Blank	-----	149	Y	
31	AP	-----	122	N	
32	AT (I)	44	207	Y	Y
33	Blank	-----	139	Y	
34	Blank	-----	113	N	Y
35	Blank	-----	-----	N	Y
36	AT (V)	-----	-----	N	
37	Blank	-----	131	Y	
38	AT (III)	-----	135	Y	Y
39	Cartridge	74	-----	Y	
40	Blank	-----	109	N	Y
41	AT (IV)	70	-----	Y	Y
42	Blank	-----	-----	N	Y
43	AP	486	-----	Y	Y
44	AT (II)	-----	-----	N	
45	AT (I)	-----	-----	N	

Mine		Signal		Detection	
Site #	MineType[a]	TNT	RDX	Results[b]	Identified[c]
46	AT (II)	-----	-----	N	
47	Blank	-----	185	Y	
48	AP	565	-----	Y	Y
49	AT (IV)	-----	-----	N	
50	Blank	-----	-----	N	Y
51	Blank	-----	-----	N	Y

(a) Five types of AT mines were present. AT (I): means Anti Tank mines of type I.
(b) Results based on the TNT and RDX signals of the previous column.
(c) In this column, Y means that the site has been correctly identified.

3.3 Level of Explosives after Ten Months of Burial

Ten month after the burial, some soil samples were collected from the surface of the mine sites containing AT mines. The analysis of the explosives were then performed off the site in a laboratory with the landmine detector prototype. The results are shown on Table III. The level of TNT in soil increased with time, probably due to the warmer weather conditions. In two cases the level of explosive was higher than the saturation level of the calibrated system at 8 ppb w/w.

TABLE IV

Residual explosives in soil after ten months

Mine Site	Mine type	TNT
# 8	AT(III)	2 ppb
# 9	AT(IV)	6 ppb
# 18	AT(I)	>8 ppb
# 21	AT(II)	3 ppb
# 23	AT(V)	8 ppb
# 45	AT(I)	>8 ppb

3.4 Detection by TED after Two and Three Years

In addition to this trial further chemical analysis of the explosive-related chemical present in the soil after two and three years has been performed (Ref. 1). Such work as also extensively done at a US mine site by Jenkins et al. (Refs. 4,5). It showed that 2,4-DNT was slightly more present in the soil than 2,4,6-TNT. This is due to the much higher volatility of DNT present in the TNT-military grade explosive. Amino derivatives of TNT resulting from biodegradation processes were mostly not present in the soil. The level of 2,4-DNT and 2,4,6-TNT was found to be below 100 ppb w/w for a large number of samples and the overall average concentration of explosive related chemicals was evaluated to be below 10 ppb w/w in the soil. The resulting vapour sources were also calculated to be below ppq v/v (10^{-15}) for 2,4-DNT and in much lower concentration for TNT.

As a consequence, the overall concentration of explosive-related chemicals present in the soils and in the vapour phase could be hardly detected by the prototype tested in this trial. Such low levels could not be detected by any existing electronic noses nor by dogs. However, the fact that dogs do find buried landmines suggests that fused landmines may leak more than an unfuzed one and lead to a much higher concentration of residual explosive in the soil. Nevertheless, the detection of buried mines by dogs in some favourable cases (warm and dry weather conditions) is still unclear to us.

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4.0 CONCLUSION

A detection trial was performed with a highly sensitive landmine detector prototype based on a soil-solvent extraction GC/ IMS analyser. The results showed that the concentration of explosives in the soil shortly after the burial of mines was below the detection limit of the system (0.8 ppb w/w for TNT and below 7.4 ppb w/w for RDX). The freshly buried mines kept in the soil under cold weather conditions were undetectable by the landmine detector prototype. Simulated studies confirmed the very low concentrations of explosive transfer to the soil by hands (below 1 ppb for many cases). Finally, from preliminary experiments it was found that the explosive level contained in the soil increases with time to 8 ppb w/w (for TNT) ten months after the burial and slightly more after two to three years. However, for all landmines buried in the soil, the explosive-related chemical were too low to be detected by the landmine prototype with a sensitivity similar to that of a dog nose. The fact that dogs do find buried landmines suggests that the presence of the fuze may lead to higher concentration of explosives in the soil through additional leak processes.

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6.0 REFERENCES

1 Désilets, S., Gagnon, N., Jenkins, T.F., Walsh, M.E., "Residual Explosives in Soils Coming from Buried Landmines", DREV TR-2000-125, March 2001 UNCLASSIFIED.

2 Durocher, R., Désilets,S., Noel, P., Bordeleau, P., Jenkins, T.F., Walsh, M., "Evaluation des vapeurs provenant de mines enfouies : Théorie de la partition et du transport des explosifs dans les sols", DREV TR-1999-120, mars 2001, SANS CLASSIFICATION.

3 Désilets, S., "Detection Trials of Buried Landmines by Trace Explosive Detection (TED)", Defence Research Establishment Valcartier, DREV TM-9721, December 1997, UNCLASSIFIED.

4 Jenkins, T.F., Walsh, M.E., Miyares, P.H., Kopczynski, J.A., Ranney, T.A., George, V., Pennington, J.C., Berry, T.E., "Analysis of Explosives-Related Chemical Signatures in Soils Samples Collected Near Buried Land Mines", US Army Corps of Engineers, Cold Regions Research Engineering Laboratory, August 2000, Technical Report ERDC TR-00-5.

5 Jenkins, T.F., Leggett, D.C., Miyares, P.H., Walsh, M.E., Ranney, T.A., George, V., "Chemical Signatures of TNT-filled Land Mines", Submitted for publication, ***Talanta*** (2000).

6 Leggett, D.C., Jenkins, T.F., Hogan, A.W., Ranney, T., Miyares, P.H., "External Contamination of Landmines by Organic Nitro-Compounds", US Ar,y Corps of Engineers, Engineer Research and Development Center, March 2000, ERDC/CRREL TR-00-2.

7 Langer, K., " A Guide to Sensor Design for Land Mine Detection, The Detection of Abandoned Land Mines: A Humanitarian Imperative Seeking a Technical Solution", Eurel International Conference, Publication No 431, p30, 7-9 October 1996.

8 Gebicke, M.E., " Unexploded ordnance: A Coordinated Approach to Detection and Clearance is Needed", US General Accounting Office, Washington, D.C. September 1995, ADA300773.

9 McFee, J.E., Das, Y., "Advances in the Location and Identification of Hidden Explosive Munition", Defence Research Establishment Suffield, Ralston, Alberta, Canada, Report No. 548, February 1991, UNCLASSIFIED.

10 McFee, J.E., Das, Y., Carruthers, A., Murray, S., Gallagher, P., Briosi, G., "CRAD Countermine R&D Study", Defence Research Establishment Suffield, Ralston, Alberta, Canada, Suffield Special Publication No 174, April 1994, UNCLASSIFIED.

11 Nacson, S., Scintrex Limited, "Feasibility Study on the Development of a Detector for Real-Time Chemical Detection of Buried Non-Metallic Landmines. Phase I : Determination of Lower Limits on Detectable Explosives Vapour Concentration", Phase I - Contract Report No W8477-2-CB08/01-SV, DND Canada, March 1993, DND ONLY.

12 Nacson, S., Scintrex Limited, "Feasibility Study on the Development of a Detector for Real-Time Chemical Detection of Buried Non-Metallic Landmines. Phase II : Vapor Emission Measurements on Bare Landmines", Phase II - Contract Report No W8477-2-CB08/01-SV, DND Canada, 11 January 1994, DND ONLY.

13 Nacson, S., Scintrex Limited, "Feasibility Study on the Development of a Detector for Real-Time Chemical Detection of Buried Non-Metallic Landmines. Phase III : Investigation of Effect of Environmental Parameters on Explosive Vapour Migration in Soils" Phase III - Contract Report No W8477-2-CB08/01-SV, DND Canada, 01 December 1995, DND ONLY.

14 Nacson, S., Scintrex Limited, "Feasibility Study on the Development of a Detector for Real-Time Chemical Detection of Buried Non-Metallic Landmines. Phase IV : Analysis of Results and Feasibility Assessment" Phase IV - Contract Report No W8477-2-CB08/01-SV, DND Canada, 01 Dec 1995, DND ONLY.

15 Jenkins, T.F., Leggett, D.C., Ranney, T.A., " Vapor Signatures from Military Explosives Part 1. Vapor Transport from Buried-Grade TNT", US Army Corps of Engineers, Cold Regions Research & Engineering Laboratory, December 1999, Special Report 99-21.

16 Lakso, H.A., "Chemical Analysis of Trace Substances from Explosives", Sweden National Defense Research Establishment, Department of ABC Protection, FOA Report C 40274-8.2, May 1990, UNCLASSIFIED.

17 Murrmann, R.P., Nakano, Y., Simpson, T.J., Leggett, D.C., Anderson, D.M., "Influence of Soil on Detection of Buried Explosives and Tunnels by Trace Gas Analysis", Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, CRREL Report 288, June 1971, UNCLASSIFIED.

18 Murrmann, R.P., Jenkins, T.F., Leggett, D.C.,"Composition and Mass Spectra of Impurities in Military Grade TNT Vapor", Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, CRREL Special Report 158, May 1971, AD 725474, UNCLASSIFIED.

19 Leggett, D.C., Murrmann, R.P., Jenkins, T.J., Barriere, R., "A Method for Concentrating and Determining Trace Organic Compounds in the Atmosphere", Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, CRREL Special Report 176, June 1972, AD 745125, UNCLASSIFIED.

20 Jenkins, T.F., O'Reilly, W.F., Murrmann, R.P., Leggett, D.C., Collins, C.I., "Analysis of Vapors Emitted from Military Mines" Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, USA, CRREL Special Report 193, 1973, AD 768709, UNCLASSIFIED.

21 O'Reilly, W.F., Jenkins, T.F., Murrman, R.P., Leggett, D.C., Barrierra, R., "Exploratory Analysis of Vapor Impurities from TNT, RDX and Composition B", Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, CRREL Special Report 194,October 1973, AD 769731, UNCLASSIFIED.

22 Jenkins, T.F., O'Reilly, R.P., Murrmann, R.P., Collins, C.I., "Detection of Cyclohexanone in the Atmosphere Above Emplaced Antitank Mines", Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, CRREL Special Report 203, April 1974, AD 778741, UNCLASSIFIED.

23 Hogan, A.W., Leggett, D.C., Lacombe, J., "Environmental Influences on Mine Detection", Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, CRREL Special Report-90-31, August 1990, UNCLASSIFIED.

24 Donovan, K., Gawronski, T., Greene, M., Brawner, C., Strickler, A., "Detection of Explosive Vapors by Enzymatic Methods-Laboratory Validation and Systems Analysis", Beckman Instruments inc., Anaheim California Advanced Technology Operations, Final Report FR-2696-101, AD-A051 582, January 1978, UNCLASSIFIED.

25 Jappinga, E. M., Patel, D. L., "Technical Transfer Report on a TNT Enzyluminescent Vapor Detection System", Army Belvoir Research Development and Engineering Center Fort Belvoir VA, Final Technical Report BRDEC-TR-2499, February 1991, ADA233444, UNCLASSIFIED.

26 Strickler, A., Greene, M., "Detection of Explosive Vapors by Enzymatic Methods", Contract Report, by Beckman Instruments Inc for US Army Mobility Equipment, FR-2696-101, January 1978, UNCLASSIFIED.

27 Shih, H. S. "Laser Detection of Explosive Vapors", Naval Coastal Systems Center, Panama City (US), Technical Report NCSC-TR-408-89, March 1991, UNCLASSIFIED.

28 Proceeding of the SPIE's 12 th Annual International Symposium on Aerospace/Defence Sensing, Simulation, and Controls, 13-17 April 1998, Orlando, Florida, USA., Detection and Remediation Technologies for Mines and Minelike Targets III, Vol 3392, papers 3392-47 to 3392-65 (1998).

29 Proceeding of the SPIE's 13 th Annual International Symposium on Aerospace/Defence Sensing, Simulation, and Controls, 5-9 April 1999, Orlando, Florida, USA., Detection and Remediation Technologies for Mines and Minelike Targets IV, Vol 3710, papers 3710-24 to 3710-41 (1999).

30 Proceeding of the SPIE's 14 th Annual International Symposium on Aerospace/Defence Sensing, Simulation, and Controls, 24-28 April 2000, Orlando, Florida, USA., Detection and Remediation Technologies for Mines and Minelike Targets V, Vol 4038, papers 4038-55 to 4038-65 (2000).

31 Spangler, G. E., "Physical Model for the Subterranean Movement of Explosive Vapors from Mines", U. S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Technical Report 2095, April 1974, AD921500L, UNCLASSIFIED.

32 Spangler, G. E., "Measurements on the Availability of TNT Vapor from Antitank Mines", U. S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Technical Report 2159, September 1975, UNCLASSIFIED.

33 Nieuwenhuizen, M. S., Olivier, R. C. M., Moes, G. W. H., Van Ruyven, L. J., Stahl, H. W. G., "TNT Vapour Measurements Above Buried Landmines Model Experiments Using Methyl-^{14}C TNT", J. Energetic Mat. 8(4), 292, 1990.

34 Phelan, J.M., Webb, S. W., "Environmental Fate and Transport of Chemical Signatures from Buried Landmines- Screening Model Formulation and Initial Simulations", Sandia National Laboratories, Albuquerque New Mexico, Report SAND97-1426 (1997).

35 Corrigan, C.D.M. (Colin), CPAD technologies. "Investigation of Explosives Detection Using Paired Gas/Liquid Chromatography and Ion Mobility Spectroscopy" DREV contract. Final Report, DIR contract # 22072EV03, Sept (1995).

36 CPAD technologies, "Construction and Optimization of an Experimental Landmine Detector Based on Ion Mobility Spectrometry" DREV Contract W7701-4-5531/01-XSK (1995-96).

37 Conrad, F. J., "Explosives Detection: The problem and Prospects", *Nuclear Materials Managements*, 13, 212, (1984).

38 Armitt, D., Mears, S. G., "The K9 Mine Detector- A Snapper's Best Friend?" Security, p 20, (1995).

39 Elias, L., "Aircraft Search Trials and Laboratoty Evaluation of Explosive Detector Dogs", The second Explosives Detection Technology Symposium and Aviation Security Technology Conference, FAA Technical Center, Atlantic City, New Jersey, 340-345, nov 12-15 (1996).

40 Fisher, D.S., Brasher, J.D., Malone, R.I., Halowell, S.F., Gresham, G., Rae, C., "The Effectiveness of Quality Control Aids in Verifying K-9 Team Explosive Detection Performance", The second Explosives Detection Technology Symposium and Aviation Security Technology Conference, FAA Technical Center, Atlantic City, New Jersey, 346-351, nov 12-15 (1996).

41 Langer, K., "A Guide to Sensor Design for Landmine Detection", Eurel International Conference to the Detection of Abandoned Land Mine, A Humanitarian Imperative Seeking a Technical Solution, p 30-32, 7-9 oct (1996).

42 Dean, E. E., Tomlinson, S. J., "The Scientific Development of an Efficient Detector Dog Through Olfaction and Behavioral Modification", Proceeding of the International Symposium on the Analysis and Detection of Explosives, FBI Academy , Quantico Virginia, March 29-31, p 451-457, 1983.

43 Smith, J. C., "Remote Detection of Explosives Using Trained Canines", Proceeding of the International Symposium on the Analysis and Detection of Explosives, FBI Academy, Quantico, Virginia, March 29-31, p 441-449, 1983.

44 Elias, L., Neudorfl, P., "Laboratory Evaluation of Portable and Walk-Through Explosives Vapour Detectors", Proceeding 3rd Int. Symp. On Analysis and Detection of Explosives, Mannheim-Neuostheim, Germany, pp. 43.1-43.19, 1989.

45 Yinon, J., Ztrin, S., "Modern Methods and Applications in Analysis of Explosives", Chapter 6 – Detection of Hidden Explosives. (see references therein), John Wiley & Sons, ISBN 0471 93894 7, (1993).

46 Armstrong, D., Baker, R. W., Mohr, J., "New Membrane Preconcentration Devices for Trace Vapor Detection Systems Phase I", U. S. Army Belvoir Research and Development Center, Fort Belvoir, Contract Report, AD-A161 042, November 1985.

47 Carr, T. W., Ed. "Plasma Chromatography", Plenum Press: New York, p259, 1984.

48 Eiceman, G. A., Karpas, Z., "Ion Mobility Spectrometry", CRC Press: Boca Raton, Fl, p228, 1994.

49 McDaniel, E. W., "Collision Phenomena in Ion Gases", John Wiley and Sons: New York, p775, 1964.

50 Mason, E. A., McDaniel, E. W., "Transport Properties of Ions in Gases", John Wiley and Sons: New York, p560, 1988.

51 U.S. Environmental Protection Agency. "Nitroaromatics and nitramines by high performance liquid chromatography", EPA Method 8330.

52 Jenkins, T.F., Walsh, M.E., "Development of Field Screening Methods for TNT, 2,4-DNT and RDX in soil", *Talanta*, Vol 39, No. 4, 419 (1992).

53 Jenkins, T.F., "Development of Simplified Field Method for thge Determination of TNT in Soils", Cold Region Research and Engineering Laboratory, Hanover, New Hampshire, USA, CRREL Special Report 90-38, (1990).

54 Teaney, G. B. and Hudack, R.T.,"Development of an Enzyme Immunoassay Based Field Screening System for the Detection of RDX in soil and Water", Air&Waste Management, Proceeding from the 87th annual meeting&exhibition, Cincinnati, Ohio, 94-RP143.05, June 19-24 (1994).

55 Jülicher, P., Mussenbrock, E., Renneberg, R., Cammann, K.,"Broadening the Antibody Specificity by Hapten Design for an Enzyme-Linked Immunoassay as an Improved Screening Method for the Determination of Nitroaromatic Residues in Soils" Analytica Chimica Acta, 315, 279 (1995).

56 Thiboutot, S., Ampleman, G., Dubé, P., Hawari, J., Spencer, B., Paquet, L., Jenkins, T.F., Walsh, M.E., "Protocol for the Characterization of Explosives-Contaminated Sites", DREV-R-9721, (1998).

57 Tomkins, B.A., "Explosives Analysis in the Environment", Encyclopedia of Analytical Chemistry, R.A. Meyers ed., John Wiley & Son Ltd., Chichester, pp 2402-2441 (2000).

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